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ASPECTS OF THE FOOD HABITS AND REARING BEHAVIOR OF UNDERYEARLING COHO SALMON (*Oncorhynchus kisutch*) IN BEAR LAKE, KENAI PENINSULA, ALASKA

by
G. B. Kyle

Number 105

Alaska Department of Fish & Game
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Don W. Collinsworth
Commissioner

Brian J. Allee, Ph.D.
Director

P.O. Box 3-2000
Juneau, Alaska 99802-2000

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ABSTRACT

In 1984 and 1985, hydroacoustic surveys and diet studies were conducted in Bear Lake to evaluate the rearing behavior and the importance of zooplankton in the diet of underyearling coho salmon. In 1984, when substantially more coho salmon juveniles were observed in the limnetic area of Bear Lake, the diet consisted primarily of zooplankton. In contrast, during 1985 when spring and seasonal zooplankton production was less and the migration of rearing juveniles to the limnetic area was curtailed; the major portion of the diet comprised of insects until mid-September, and zooplankton thereafter, until the end of the seasonal growth period (late-October). In 1984, 80,000 fewer and larger hatchery fingerlings released into Bear Lake produced a significantly ($p = 0.05$) larger fish at the end of the summer growing season than in 1985; however, the maximal daily growth rates in 1984 and 1985 were quite similar. A pen rearing study conducted in 1985 provided evidence that rearing coho salmon restricted to a zooplankton diet can not only survive over the summer until mid-fall, but also can grow to a respectable size; despite a relatively high fish density and the possibility of limited entry of large-size zooplankton in the pens. It is apparent from these studies in Bear Lake that zooplankton provides an important food source for rearing coho salmon juveniles that can be either primary or secondary to insects. In addition, zooplankton has the potential to affect daily and seasonal fish growth, and influence the rearing behavior of juvenile coho salmon.

INTRODUCTION

During 1981-1986, Bear Lake located on the Kenai Peninsula near Seward, Alaska, was treated with controlled additions of inorganic nutrients during the summer growing season to increase autochthonous production (Kyle and Koenings 1983). This project was directed toward providing more food for stocked fingerling coho salmon (*Oncorhynchus kisutch*) to subsequently enhance the return of adult coho salmon to support the marine, recreational sport fishery in Resurrection Bay.

The assumption in most lakes supporting coho salmon is that juveniles are seldom found far from shore (Gribanov 1948; Dvinin 1949; Mason 1974; Zorbidi 1977), and feed primarily on aquatic insects (Ricker 1937; Gribanov 1984; Forester and Ricker 1953; Mason 1974). In addition, Mason (1974) found that the almost exclusive dependence of juvenile coho salmon on allochthonous, wind-borne insects for food, precluded any connection between rearing coho salmon and the trophic levels affected by the fertilization program at Great Central Lake. However, the prevalence of both sockeye salmon (*O. nerka*) and sticklebacks (*Gasterosteus aculeatus*) in the limnetic area of Great Central Lake may have restricted the diet of juvenile coho salmon to littoral food items (insects) through special habitat or behavioral partitioning. Moreover, in lakes with outlet barriers and devoid of sockeye salmon and sticklebacks, juvenile coho salmon have been found to grow at rates of 1 mm per day on a diet of primarily zooplankton (Crone 1981; Crone and Koenings 1985).

In the case of Bear Lake, which is similar to a barriered lake in that since rehabilitation, the entry of undesirable fish in the lake has been controlled by a permanent weir; the food habits and rearing behavior of stocked coho salmon fingerlings have not been investigated. In view of the lake fertilization project, which was aimed at increasing/stabilizing age-1 smolt production through increasing desirable food for zooplankton; the premise was that juvenile coho salmon will sometime during their freshwater residence feed limnetically on zooplankton and benefit from the increased zooplankton forage resulting from the addition of nutrients.

The purpose of fishery investigations conducted in 1984 and 1985 was to: 1) estimate the juvenile coho salmon population and monitor rearing distributions in Bear Lake throughout the summer growing season (June-October); 2) determine the importance of zooplankton in the diet of underyearling coho salmon rearing in Bear Lake throughout the summer growing season through electivity indices; and 3) determine and compare the growth of fingerling coho salmon restricted on a diet of zooplankton in net pens with that of cohorts feeding on insects and zooplankton in the lake. Results of these investigations are presented and discussed in this report.

Study Site Description-- Bear Lake is the largest clearwater lake in the Resurrection River drainage and is located on the Kenai Peninsula 9 km north of the city of Seward (60° 14'N, 194° 20'W) in Southcentral Alaska (Figure 1). In 1963, the lake was rehabilitated (rotentoned) to eradicate undesired predator and/or competitor fish species. Since then, coho salmon fingerlings have been stocked almost continuously every year. In 1984, a total of 220,000 coho salmon fingerlings (1,220/ha) were stocked at a size of 640/kg, while in 1985, 300,446 coho salmon fingerlings (1,670/ha) were stocked as two groups at sizes of 860/kg and 1,455/kg. Historically, most of the coho salmon fingerlings released in Bear Lake have emigrated as smolts after only one year of residence. Other fish species known to occur in Bear Lake include Dolly Varden (*Salvelinus malma*) sockeye salmon, and various species of sculpin (*Cottus* spp.); however, coho salmon dominate the lake.

The lake lies at an elevation of 10 m and has a surface area of 180 ha (445 acres), a mean depth of 10 m, and a volume of 18.7×10^6 m^3. Bear Lake is characterized as oligotrophic in the euphotic zone; however, in the hypolimnion the lake is meso-eutrophic, due to a shallow strata of unmixed water below 12 m in depth (Kyle and Koenings 1983). The water renewal is primarily by the melting of ice and snowmelt in the spring and by rainfall in the autumn. Usually, maximum outlet discharge

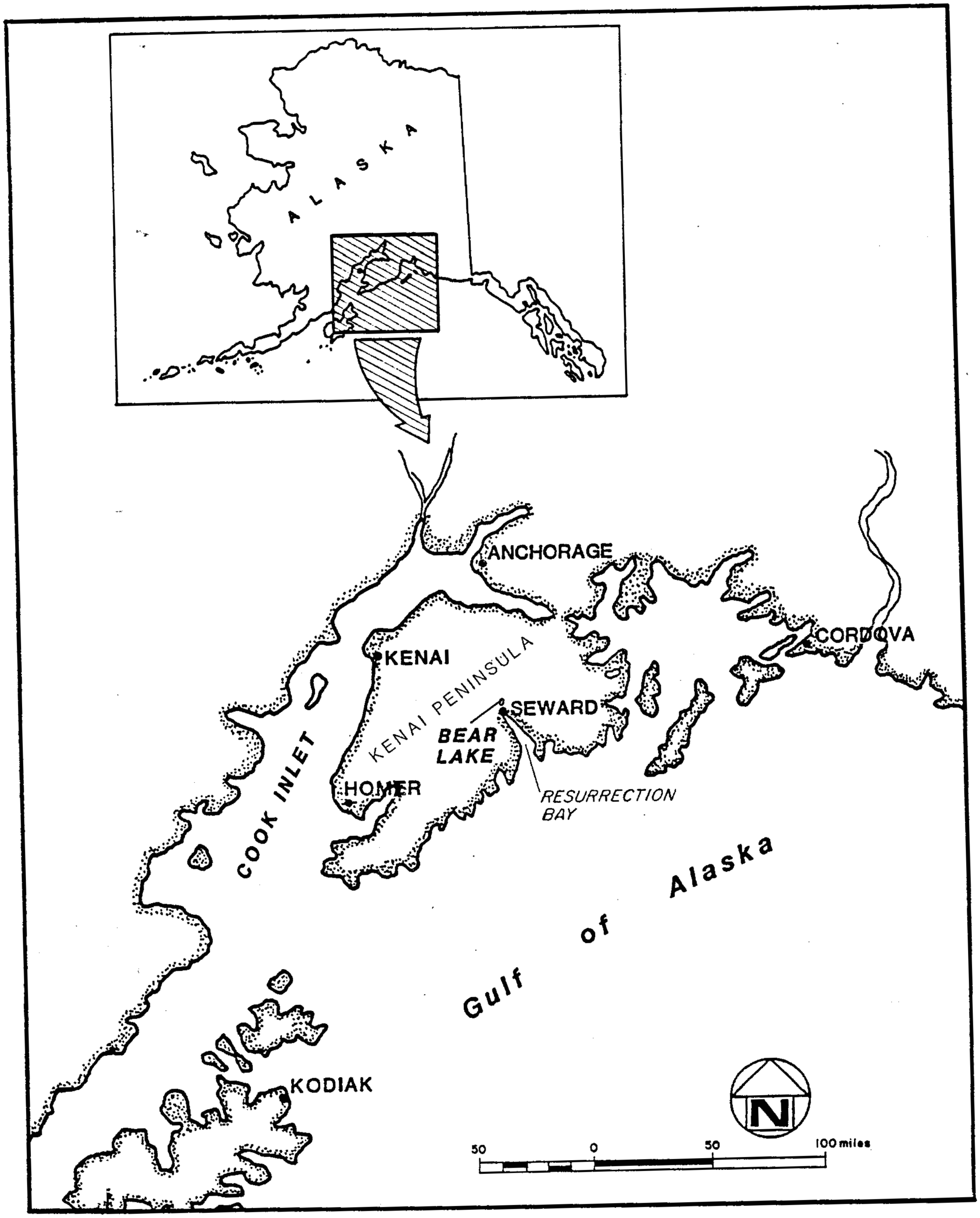

Figure 1. Location of Bear Lake on the Kenai Peninsula in Southcentral Alaska.

occurs in the autumn with the spring discharge accounting for only 15% of the total during the ice-free period (May-November). The yearly annual precipitation is 216 cm, and the average water residence time is estimated at 0.8 years. The littoral area defined by the euphotic zone depth represents 38% of the total surface area of the lake.

METHODS

Juvenile Coho Salmon Population Estimates and Rearing Distributions-- Population estimates and rearing distributions of juvenile coho salmon in Bear Lake were obtained through the application of hydroacoustic assessment techniques (Kyle 1990). Hydroacoustic surveys were conducted during July, September, and October of 1984 and 1985. A Simrad® EY-M (70 kHz) echosounder was used in 1984 while a BioSonics Model 105 (420 kHz) echosounder was used in 1985. Both sounders were equipped with a time-varied-gain circuit, which controls the spreading and attenuation losses of the acoustic signal with distance. The transducers were of similar beam widths (11° and 15°) and were system-calibrated. Gain settings were set in the field to achieve optimum signal-to-noise levels, and at a setting in which fish could be detected in a wide range of signal sizes. The transducers were mounted in a towing body and suspended 1 m below the lake surface, which allowed depths greater than 2 m below the lake surface to be insonified. Sampling volume of the hydroacoustic systems was determined by the duration-in-beam method (Crittenden et al. 1988, Thorne 1988).

Hydroacoustic data were collected each year from the same seven cross-lake transects (Figure 2), and in half of the surveys these transects were replicated. In addition, fish distribution information nearshore was achieved through the deployment of a 2° transducer in a side-scanning position. The monitoring of fish signals was done with

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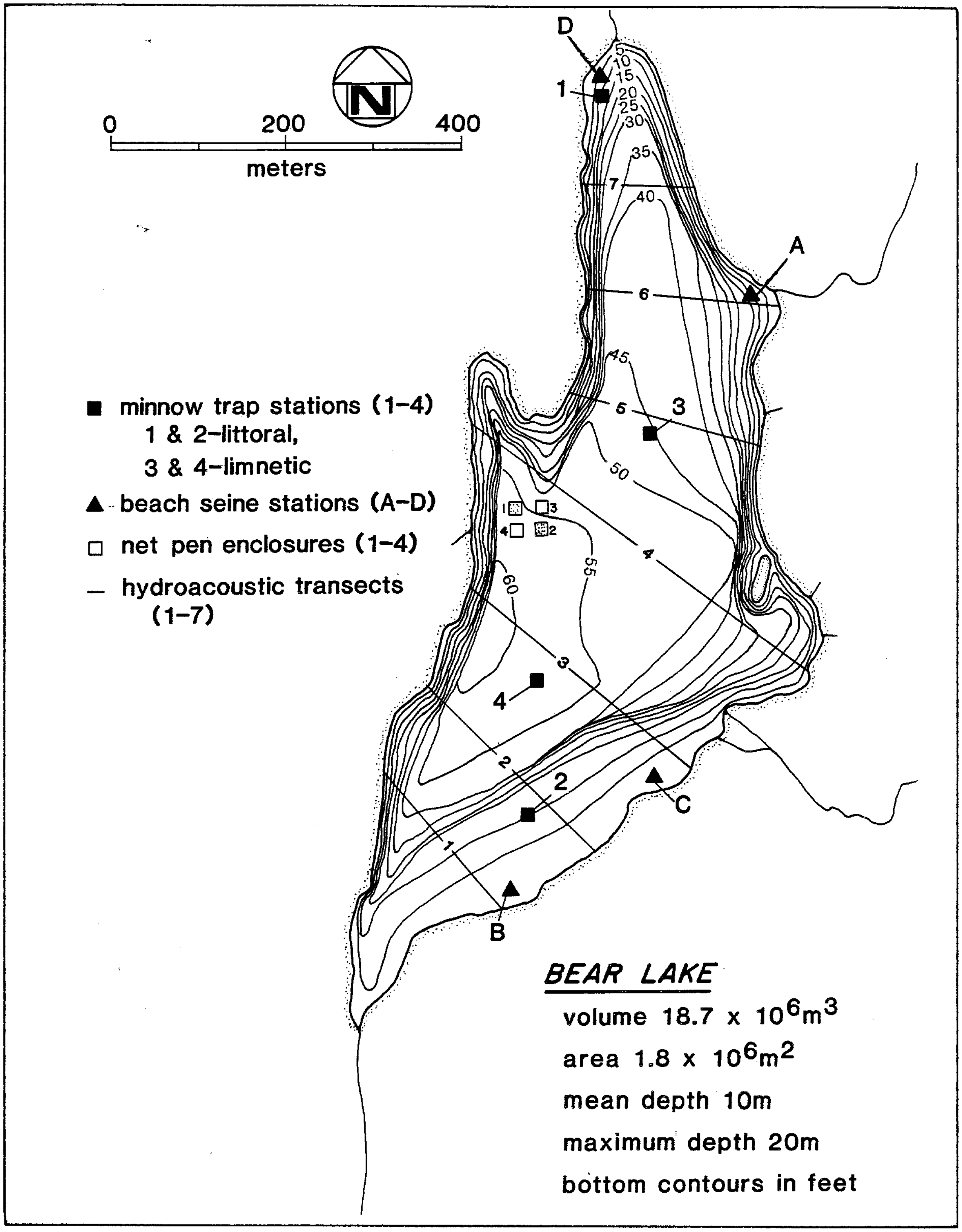

Figure 2. Morphometric map of Bear Lake showing locations of hydroacoustic transects, trap and seine stations, and net pens.

an oscilloscope, while signal recording was done on analog- or digital-format tapes, and on a chart recorder. All acoustic surveys were done during darkness to reduce fish avoidance of the sampling gear. To assist in staying on course during transecting and to ensure transect replication, yellow flashing lights were placed on both sides of each transect.

The echo-counting technique (Saville 1977) was used to generate population estimates, as in all surveys fish densities were low. In the echo-counting technique, a counting threshold is established on the basis of target amplitudes and noise levels, which in our surveys was normally 30 decibels below the largest targets. The number of echoes from each fish, and the number of detections per fish were then counted in several depth intervals, beginning at 2 m below the lake surface. Echo counts were made along each third (eastern, middle, and western subsection) of every transect. Fish densities were summed by depth intervals for each transect and extrapolated by the lake surface area represented by each transect to obtain a population estimate. In surveys that transects were replicated (September 1984 and 1985, October 1985), the mean population estimates and 95% confidence intervals were based on fish densities from the replicates for all depth strata (Kyle 1990). In the other surveys (July 1984 and 1985; October 1984), the population estimates and associated confidence intervals were calculated by collapsing the mean fish density for each transect into strata after Bazigos (1976).

Juvenile Coho Salmon Growth, Prey Composition, and Zooplankton Selectivity-- A 30-m beach seine and minnow traps with enclosed bait (Gray et al. 1984) were used at set locations in both 1984 and 1985 to capture underyearling coho salmon (juveniles) rearing in Bear Lake (Figure 2). Juveniles were sampled at least once per month during June-October for growth information and food composition. Following capture, coho salmon juveniles were anesthetized with tricaine methanesulfonate (MS-222), weighed to the nearest 0.1 g, and measured to the nearest millimeter. Growth was expressed in millimeters and grams per day, and the average daily increase in weight was expressed as a percentage of the initial weight (G′) after

Winberg (1956). In addition, paired length and weight measurements of coho salmon juveniles were used to determine the ponderal index (K), commonly referred to as the coefficient of condition after (Bagenal 1978).

The technique of gastric lavage (Light et al. 1983) was used to remove stomach contents from juvenile coho salmon. The gastric lavage apparatus of Light et al. (1983) was modified to accommodate smaller-size fish (Koenings et al. 1987). After removal, the stomach contents of individual fish were preserved in a vial containing 10% neutralized formalin. The stomach contents of each fish were identified, and zooplankton prey were measured for body size as described in Koenings et al. (1987). Replicate zooplankton samples from lake stations 3 and 4 (Figure 2) were collected once each month (concurrent with fish samples), using a 0.20-m diameter, conical plankton net with 153-μm mesh. Finally, the Ivlev (1961) electivity index was used to determine the feeding selectivity of juvenile coho salmon on different taxa of macro-zooplankton. In addition, this index was used to determine size-selectivity of the various macro-zooplankton taxa consumed by foraging juveniles.

Pen Rearing Study-- In 1985, a rearing study was conducted on underyearling coho salmon to determine the daily and seasonal growth on a diet restricted to macro-zooplankton. The study consisted of placing 20 hatchery-produced fingerlings each in two replicate net pens (1 and 2), and comparing zooplankton density, zooplankton size, and fish growth in these pens, with that in pens without fish (3 and 4), and with zooplankton and fish sampled in the lake. The density of fingerlings in pens 1 and 2 was equivalent to 14,000/ha, or 8 times the density of fish released in Bear lake during 1985. The net pens were made of 0.3-cm diameter, circular-mesh nylon netting, measured 2.4 m by 2.4 m by 2.4 m, and were held in place by a rigid steel frame. The pens were suspended at the surface with styrofoam logs, anchored to the bottom with sand bags, and placed in an area of the lake that offered maximum protection against adverse weather, yet represented the limnetic zone (Figure 2). Size and foregut sampling on the fingerlings was conducted approximately once every two weeks during 0800 and 1000 h. Duplicate zooplankton tows were taken with the same net that lake samples were (0.2-m diameter, 153-μm mesh), from the bottom of the enclosure to the lake surface, in all of the pens and in the lake at the same time. At least 10 fingerlings from pen 1 and pen 2 were measured for length and weight, and sampled for gut contents. All nets were rigorously cleaned with a stiff brush at least every two weeks, and once per week during peak periphyton growth. Finally, fish growth, zooplankton abundance, and zooplankton electivity indices were compared between fingerlings reared in the pens and cohorts in the lake during June-October.

RESULTS AND DISCUSSION

Juvenile Coho Salmon Population Estimates and Rearing Distributions-- Seasonal estimates of juvenile coho salmon rearing in Bear Lake indicated that more juveniles were rearing in the limnetic zone during the later part of the growing season in 1984 than in 1985, despite the stocking of ~80,000 more fingerlings in 1985. That is, in July of both years the limnetic population estimates were quite similar (16,132 ± 2,557 in 1984; 15,650 ± 1,745 in 1985); however, in the September and October surveys, estimates of juvenile coho salmon were approximately 3.5-fold greater in 1984 than in 1985 (Figure 3). In addition, with the exception of fewer rearing fish near the surface in July of 1985, the vertical distribution pattern of rearing fish was fairly consistent for both years (Figure 4A). The vertical distribution was linear during July and October with the highest densities near surface, while in September the fish were concentrated at mid-depth (10-12 m).

The evident difference in the limnetic population estimates of juvenile coho salmon during September and October of 1984 compared to 1985, is most likely due to seasonal rearing distribution differences. During the three surveys of 1984, mean fish densities in the eastern subsection of the transects, which is comprised of more littoral area, remained fairly constant, while in the middle and western subsections, mean fish densities increased significantly during the summer season (Figure 4B). Whereas in 1985, the horizontal distribution pattern in the middle subsection

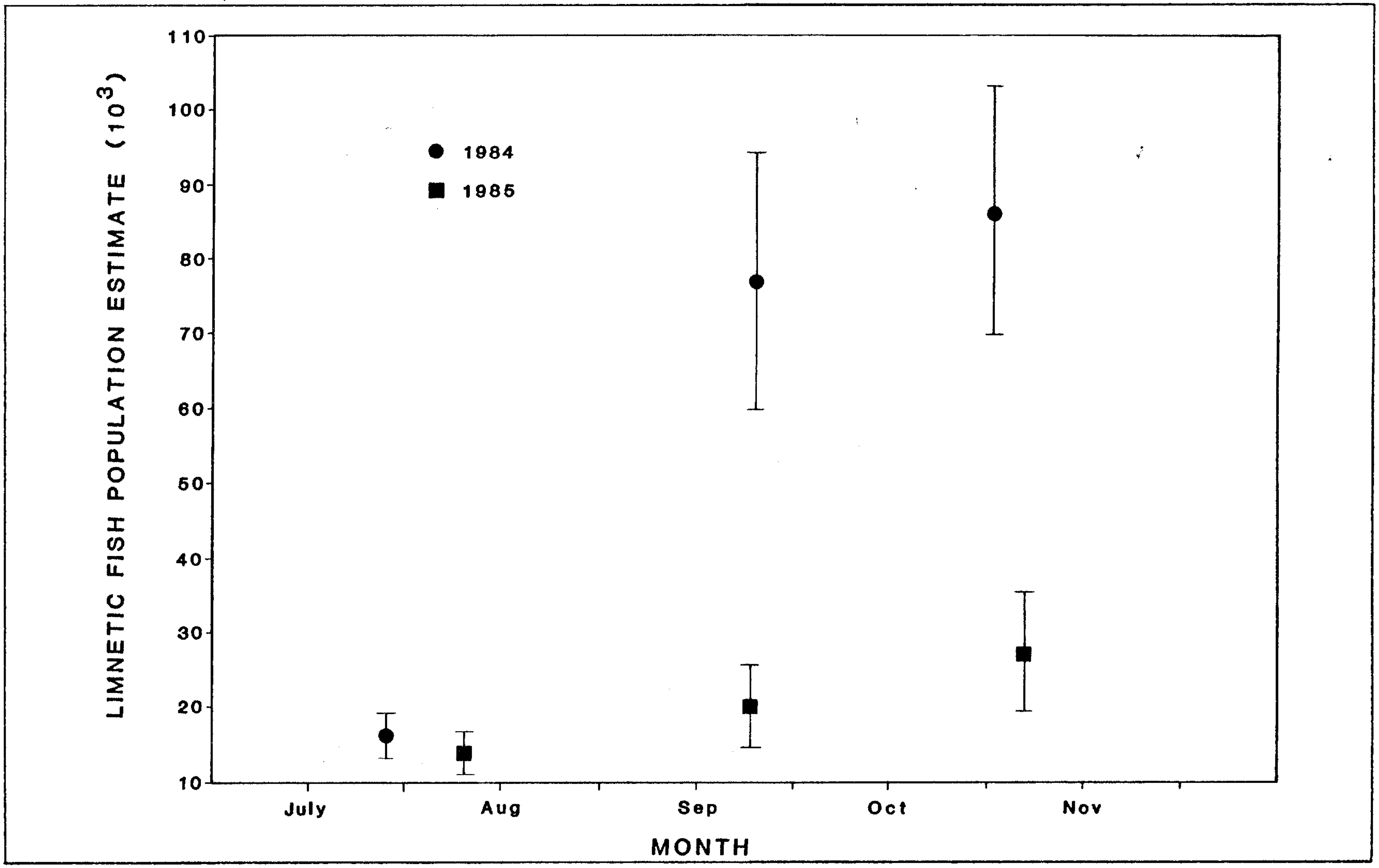

Figure 3. Limnetic population estimates and 95% confidence intervals (I) of juvenile coho salmon rearing in Bear Lake during 1984 and 1985.

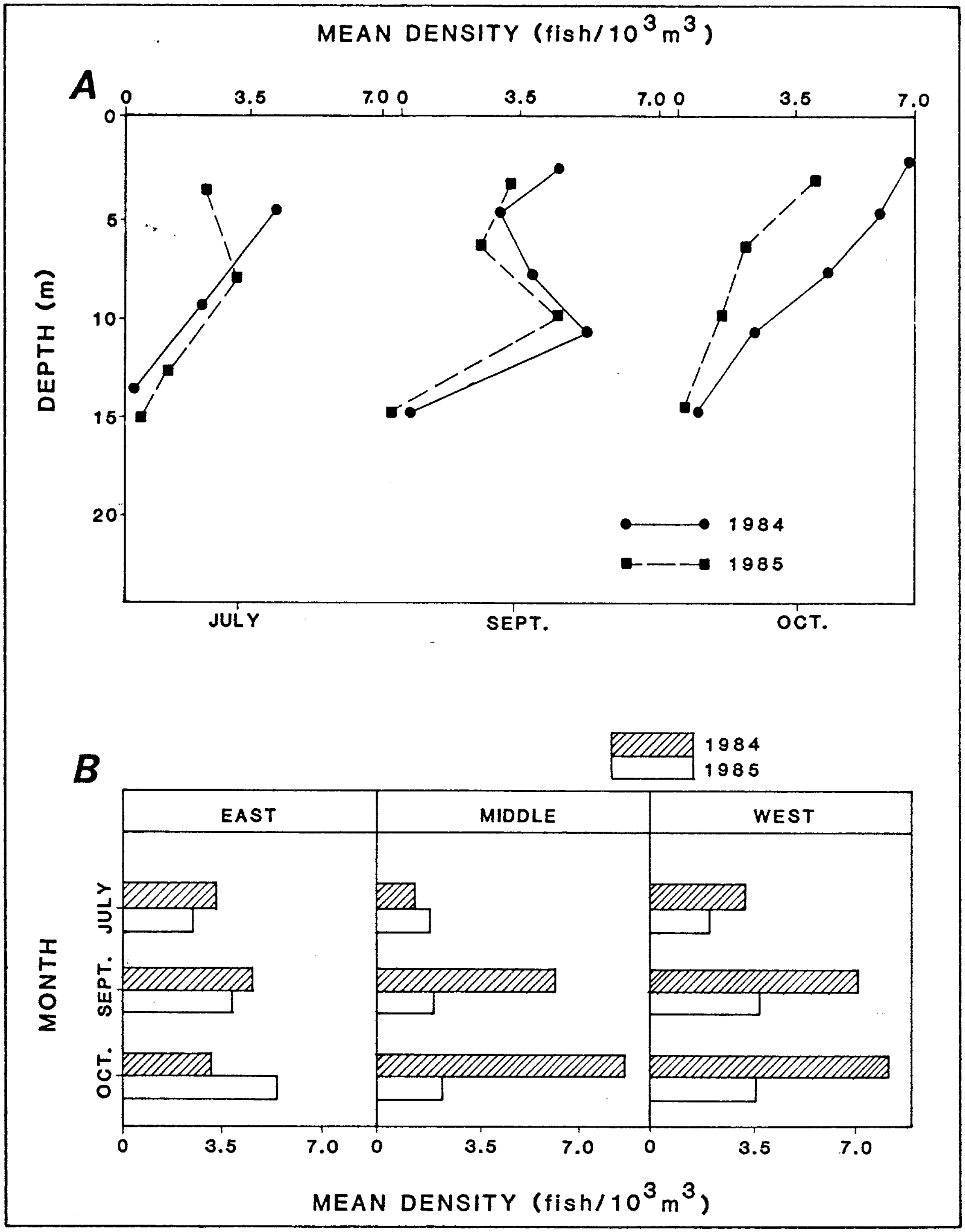

Figure 4. Vertical (A) and horizontal distributions (B) of juvenile coho salmon rearing in Bear Lake during 1984 and 1985.

remained constantly low, while in the outer subsections, especially the eastern subsection, mean fish densities increased over the summer. Moreover, side-scan echograms of the major cove on the eastside of the lake in September of 1984 indicated that few fish were in this transitory area between limnetic and littoral areas (Figure 5A). In contrast, the echogram of the same area in 1985 indicated very high densities of fish in the transitory area (Figure 5B). Considering that the hydroacoustic equipment is limited in detection in the down-scan mode to depths greater than 2 m, many of the fish in the nearshore areas in 1985 were undetected, and not included in the limnetic fish population estimates. Thus, the horizontal distribution data strongly suggests that in 1985, spring-to-fall survival was not necessarily less, as indicative of the lower limnetic fish estimates, but that the large offshore migration of rearing coho salmon to the limnetic area was curtailed in 1985.

Seasonal Growth, Prey Composition, and Zooplankton Selectivity of Underyearling Coho Salmon Rearing in Bear Lake-- The daily growth rate of underyearling coho salmon stocked in Bear Lake was relatively higher during the first month of rearing (June) in 1984 than in 1985, as the mean daily increase in length (mm) and weight (%) was 0.45 mm and 0.8% in 1984, and 0.20 mm and 0.6% in 1985 (Figure 6). However, during July when the daily growth rate peaked in both years, the mean daily increase in length was 0.78 mm in 1984 and 0.65 mm in 1985, while the daily percent increase in weight (G′), which more directly represents ichthyomass production (Crone 1981), was 1.5% in 1985 compared to 1.1% in 1984. After July, the daily growth pattern was similar both years with an almost linear decline until the end of October when growth ceased. The seasonal daily growth rate during 1984 averaged 0.38 mm and 0.07 g, while during 1985 the seasonal growth rate averaged 0.34 mm and 0.05 g (Table 1). At the end of the growing season (October), the size of underyearling coho salmon in 1984 was significantly (Mann-Whitney U-test; $p = 0.05$) larger than in 1985. Finally, the coefficient of condition (K) of underyearlings fluctuated dramatically within and during both years, ranging from 1.02-1.25 during 1984 and 0.99-1.23 during 1985 (Figure 6).

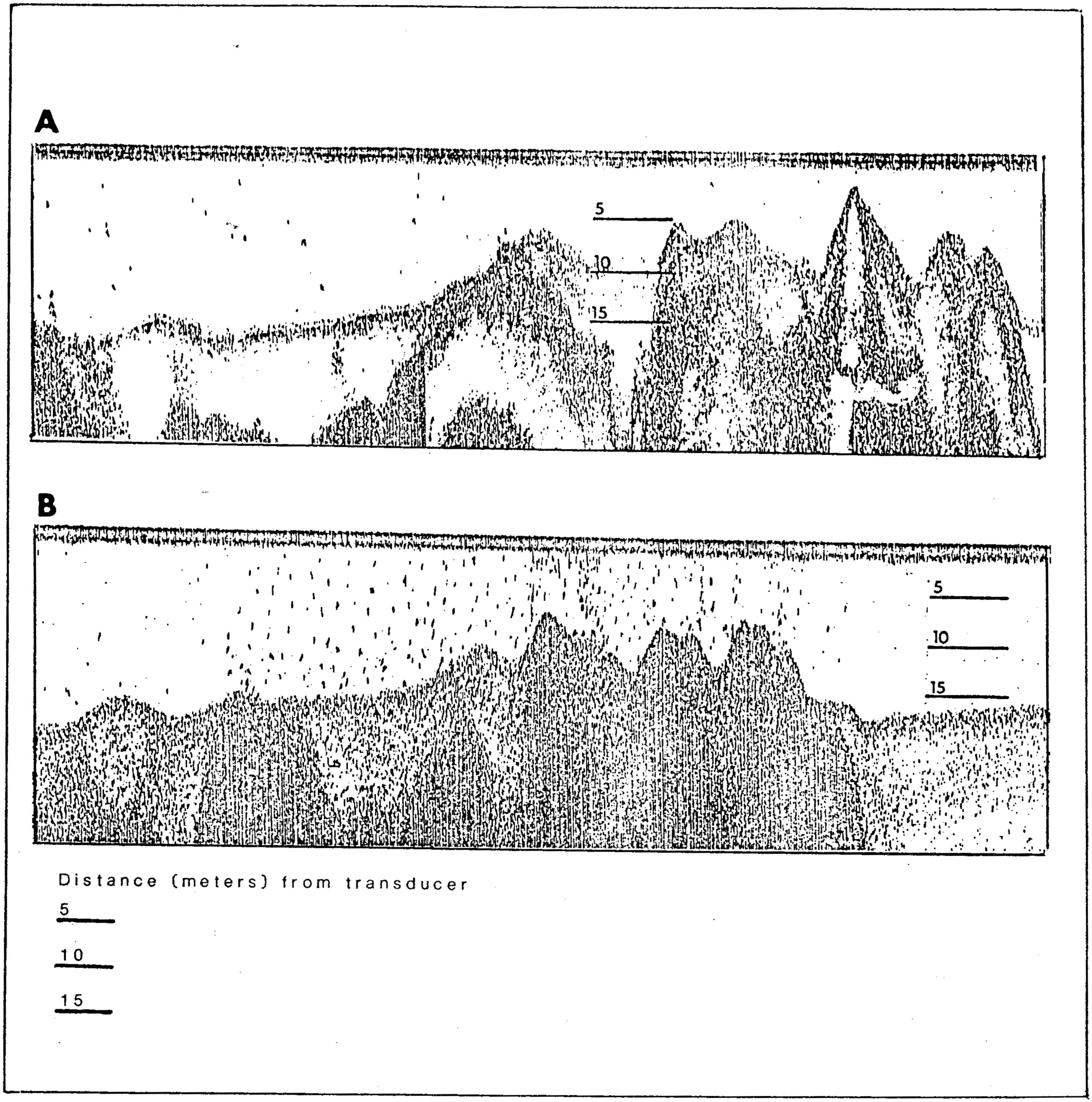

Figure 5. Side-scan echograms showing relative fish density in the major cove on the eastside of Bear Lake in September of 1984 (A) and 1985 (B).

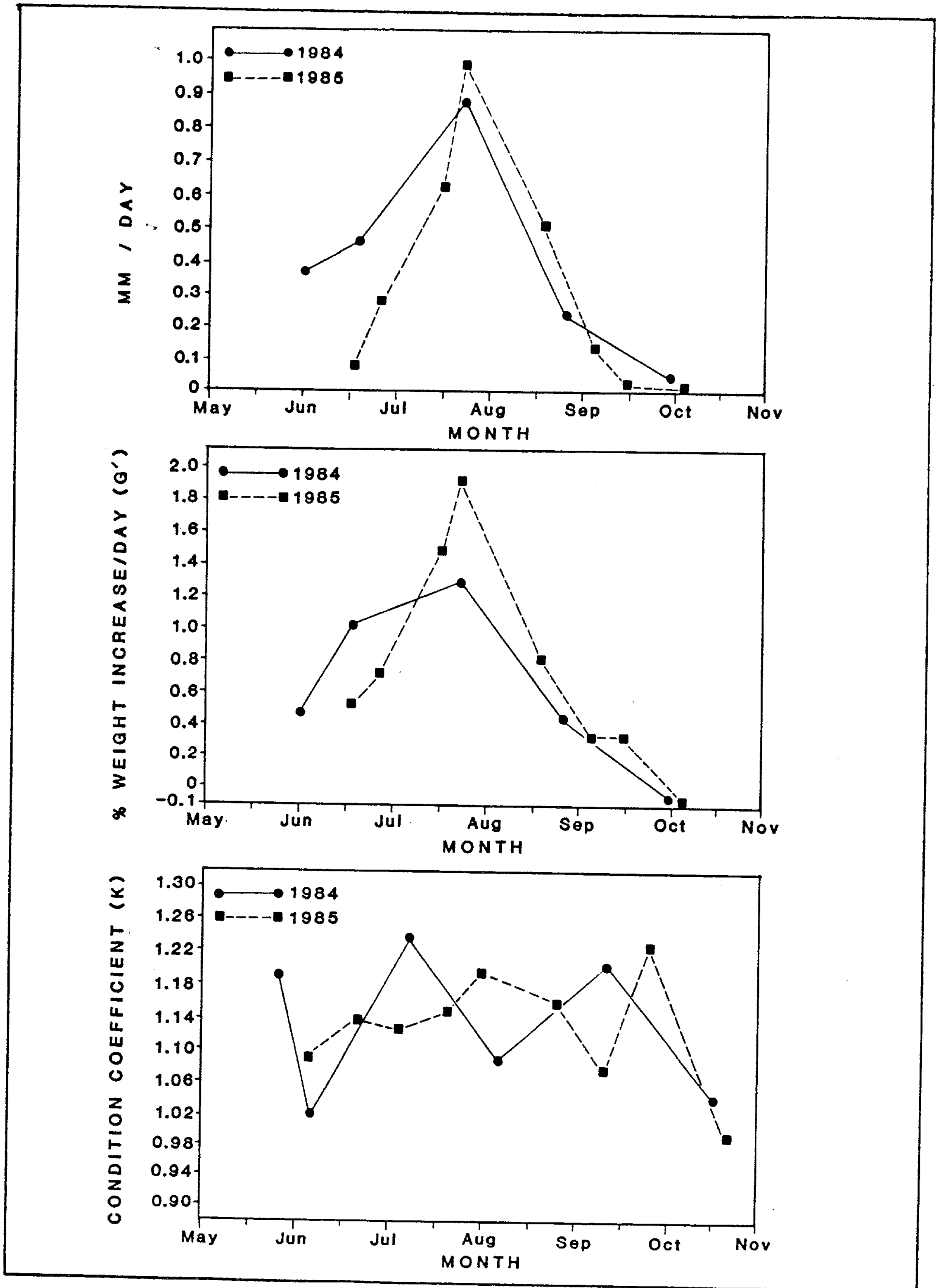

Figure 6. Daily growth rates and seasonal condition coefficients for underyearling coho salmon rearing in Bear Lake during June-October of 1984 and 1985.

Table 1. Mean size and daily growth rate for underyearling coho salmon rearing in Bear Lake during 1984 and 1985.

Year/ date	Mean length (mm)	Mean weight (g)	Daily Growth Rate Length (mm)	Daily Growth Rate Weight (g)
1984				
24 May	49	1.4		
			0.37	0.02
05 Jun	54	1.6		
			0.41	0.06
10 Jul	67	3.7		
			0.88	0.17
08 Aug	92	8.5		
			0.25	0.12
12 Sep	101	12.4		
			0.08	0.02
17 Oct	104	11.6		
		Seasonal	0.38	0.07
1985				
05 Jun	47	1.1		
			0.06	0.007
20 Jun	47	1.2		
			0.28	0.02
03 Jul	51	1.5		
			0.63	0.07
18 Jul	61	2.6		
			1.01	0.17
01 Aug	75	5.0		
			0.49	0.10
22 Aug	86	7.2		
			0.29	0.05
11 Sep	91	8.1		
			0.00	0.07
26 Sep	91	9.1		
			0.15	-0.02
23 Oct	95	8.5		
		Seasonal	0.34	0.05

Based on the sampling of underyearling coho salmon rearing in Bear Lake during 1984, insects, and in particular, chironomids were the most abundant and frequently occurring food item during June and July, when juveniles were rearing nearshore (Table 2). The percent composition of chironomids found in stomachs of all underyearlings sampled during June and July was quite similar; 53.3% and 52.3%, respectively of the total diet. The frequency of occurrence averaged 57.5% in June and 62.5% in July. However, after July when a significant number of juveniles migrated offshore (Figures 3 and 4B), the diet abruptly shifted to zooplankton, most notably cladocerans. For example, beginning in early August and continuing thereafter, the highest frequency of prey occurrence shifted from insects to zooplankton, and cladocerans composed of 66.4% to 95.3% of the total diet (Table 2).

During 1985, juvenile coho salmon appeared to remain along the shoreline of Bear Lake later in the year than in 1984, as juveniles were captured by seining through September (Table 3). As in 1984, chironomids were the most abundant insect found in juveniles during 1985, but unlike 1984, the percent diet composition of chironomids remained high (averaged 50%) through mid-September (Table 3). Although there were high compositions of zooplankton prey (mainly cladocerans) found in juveniles sampled before mid-September, it appeared zooplankton as a food source was secondary to insects through mid-September of 1985 compared to 1984. However, the end of September and October sampling dates revealed that cladocerans were more prevalent in the diet of juveniles.

During 1984, active selection (positive electivity indice) of zooplankton prey by underyearling coho salmon rearing in Bear Lake was infrequent in June and July, while during August-October active selection of zooplankton prey was common (Figure 7A). In addition, the size range of zooplankton prey that were actively selected varied by zooplankton taxa, but overall ranged from 0.50 mm for *Bosmina* to >1.90 mm for *Cyclops* (Figure 7B). In 1985, active selection of zooplankton prey was less, as there were more negative electivity indices for all zooplankton taxa over the

Table 2. Percent composition (n/N%) and frequency of occurrence (f/n%) of prey found in stomachs of underyearling coho salmon collected in Bear Lake during June-October, 1984.

Sample Date	Sample gear and location	Sample size	Percentage of fish containing food	Mean number of food items/fish	Zooplankton: Copepoda (n/N%)	Zooplankton: Copepoda (f/n%)	Zooplankton: Cladocera (n/N%)	Zooplankton: Cladocera (f/n%)	Zooplankton: Other (n/N%)	Zooplankton: Other (f/n%)	Insects: Chironomidae (n/N%)	Insects: Chironomidae (f/n%)	Insects: Other (n/N%)	Insects: Other (f/n%)	Insects: Unidentified (n/N%)	Insects: Unidentified (f/n%)	Other food items (n/N%)	Other food items (f/n%)
05 Jun	Seine A	10	100.0	14	0.0	0.0	0.0	0.0	1.4	10.0	29.1	80.0	31.2	70.0	34.0	60.0	4.3	40.0
	Seine B	10	100.0	31	1.0	10.0	0.0	0.0	1.3	20.0	63.8	100.0	11.5	70.0	21.2	70.0	1.3	40.0
	Seine C	10	100.0	11	5.3	10.0	0.0	0.0	0.0	0.0	53.1	100.0	8.0	40.0	30.1	70.0	3.5	40.0
	Seine D	10	100.0	5	2.1	10.0	0.0	0.0	2.1	10.0	41.7	80.0	14.6	50.0	22.9	40.0	16.7	50.0
	Seines A-D	40	100.0	15	1.6	7.5	0.0	0.0	1.1	10.0	53.3	90.0	15.6	57.5	25.9	60.0	3.6	42.5
10 Jul	Seine A	10	100.0	23	5.9	10.0	0.4	10.0	3.0	40.0	29.5	100.0	25.2	80.0	31.6	100.0	9.4	50.0
	Seine B	10	100.0	21	0.0	0.0	0.0	0.0	0.0	0.0	64.2	100.0	1.4	30.0	26.2	90.0	11.9	70.0
	Seine C	10	100.0	28	0.0	0.0	1.1	30.0	0.0	0.0	85.5	100.0	2.8	60.0	2.1	40.0	8.5	40.0
	Seine D	10	100.0	14	0.0	0.0	13.1	20.0	0.7	10.0	40.1	100.0	9.5	50.0	21.2	90.0	14.6	30.0
	Seines A-D	40	100.0	23	0.2	5.0	3.5	12.5	0.9	12.5	52.3	100.0	9.6	62.5	19.0	85.0	10.5	55.0
08 Aug	Trap 1	10	90.0	17	4.6	40.0	4.6	60.0	49.7	40.0	4.0	30.0	22.3	60.0	9.1	50.0	5.7	50.0
	Trap 2	19	78.9	73	32.2	15.8	71.4	31.6	5.6	15.8	0.2	11.1	0.6	21.1	0.3	15.8	0.7	26.3
	Trap 3	3	66.0	53	0.6	33.3	95.6	66.7	0.0	0.0	1.9	66.7	0.6	33.3	0.0	0.0	0.0	0.0
	Traps 1-3	32	83.9	56	26.2	22.6	66.4	38.7	9.5	22.6	0.7	21.9	2.8	35.5	1.1	22.6	1.1	32.3
12 Sep	Trap 2	5	100.0	154	0.0	0.0	98.3	60.0	0.4	20.0	0.4	60.0	0.1	20.0	0.3	20.0	0.5	20.0
	Trap 3	10	100.0	79	0.0	0.0	93.8	20.0	1.5	60.0	0.2	20.0	0.6	30.0	0.5	40.0	2.7	70.0
	Trap 4	7	100.0	14	1.2	14.3	79.1	28.6	1.1	14.3	2.2	28.6	9.3	28.6	7.0	85.7	0.0	0.0
	Traps 2-4	22	100.0	75	0.1	4.5	95.3	45.5	1.0	36.4	0.3	31.8	0.9	27.3	0.7	50.0	1.5	36.4
17 Oct	Trap 3	10	80.0	13	32.6	20.0	32.6	50.0	8.3	40.0	0.0	0.0	3.8	30.0	0.0	0.0	18.9	50.0
	Trap 4	12	100.0	26	0.3	8.3	94.0	33.3	1.0	16.7	0.0	0.0	1.0	16.7	0.3	8.3	2.2	41.7
	Traps 3-4	22	90.9	20	10.8	13.6	75.8	45.5	3.1	27.3	0.0	0.0	1.8	22.7	0.2	4.5	7.2	45.5

Table 3. Percent composition (n/N%) and frequency of occurrence (f/n%) of prey found in stomachs of underyearling coho salmon collected in Bear Lake during June-October, 1985.

Sample date	Sample gear and location	Sample size	Percentage of fish containing food	Mean number of food items/ fish	Zooplankton: Copepoda (n/N%)	Zooplankton: Copepoda (f/n%)	Zooplankton: Cladocera (n/N%)	Zooplankton: Cladocera (f/n%)	Zooplankton: Other (n/N%)	Zooplankton: Other (f/n%)	Insects: Chironomidae (n/N%)	Insects: Chironomidae (f/n%)	Insects: Other (n/N%)	Insects: Other (f/n%)	Unidentified (n/N%)	Unidentified (f/n%)	Other food items (n/N%)	Other food items (f/n%)
19 Jun	Seine A	21	100.0	21	30.0	14.3	0.5	9.5	0.0	0.0	42.7	76.2	24.1	90.5	0.2	4.8	2.5	38.1
	Seine C	10	100.0	23	14.0	20.0	0.0	0.0	0.0	0.0	57.9	100.0	27.2	90.0	0.0	0.0	0.9	20.0
	Seines A-C	31	100.0	22	24.6	16.1	0.3	6.5	0.0	0.0	47.9	83.9	25.2	90.0	0.1	3.2	25.2	96.8
03 Jul	Seine A	11	100.0	10	19.3	18.2	4.4	36.4	0.9	9.1	32.5	81.8	39.5	63.6	0.9	9.1	2.6	27.3
	Seine C	11	100.0	50	1.9	18.2	54.4	18.2	0.2	9.1	35.2	100.0	7.4	81.8	0.4	18.2	0.5	27.3
	Seines A-C	22	100.0	30	4.9	18.2	46.0	22.7	0.4	9.1	34.8	95.5	12.9	77.3	0.5	13.6	0.9	27.3
18 Jul	Seine B	20	100.0	56	0.0	0.0	27.3	95.0	0.0	0.0	63.2	100.0	3.6	75.0	0.4	20.0	5.5	90.0
01 Aug	Seine B	12	100.0	314	0.0	0.0	0.0	0.0	0.0	0.0	97.1	100.0	1.9	100.0	0.1	16.7	0.9	75.0
22 Aug	Seine B	35	100.0	127	0.1	5.7	1.5	48.6	0.0	0.0	53.2	100.0	35.8	100.0	1.4	57.1	7.9	94.3
	Trap 1	5	80.0	136	0.0	0.0	97.5	80.0	0.0	0.0	0.3	40.0	0.1	20.0	0.1	20.0	1.9	60.0
11 Sep	Seine B	15	100.0	60	0.2	6.7	3.5	73.0	0.0	0.0	59.5	100.0	28.6	100.0	0.4	26.7	7.4	86.7
	Trap 2	21	85.7	10	0.6	4.8	47.0	33.3	0.0	0.0	9.5	33.3	4.2	19.0	6.0	19.0	33.3	47.6
27 Sep	Seine A	33	97.0	10	16.4	3.0	8.4	6.1	0.0	0.0	9.6	48.5	42.1	87.9	18.9	45.5	4.6	39.4
	Trap 1	29	69.0	19	29.1	10.3	56.4	27.6	0.2	3.4	2.3	27.6	4.5	27.6	0.5	10.3	7.0	37.9
	Trap 2	10	90.0	10	1.4	10.0	0.0	0.0	1.4	10.0	41.1	70.0	1.4	10.0	1.4	10.0	53.4	80.0
22 Oct	Trap 2	18	87.9	33	0.0	0.0	93.4	33.3	0.0	0.0	4.7	50.0	0.2	5.6	0.3	11.1	1.4	22.2

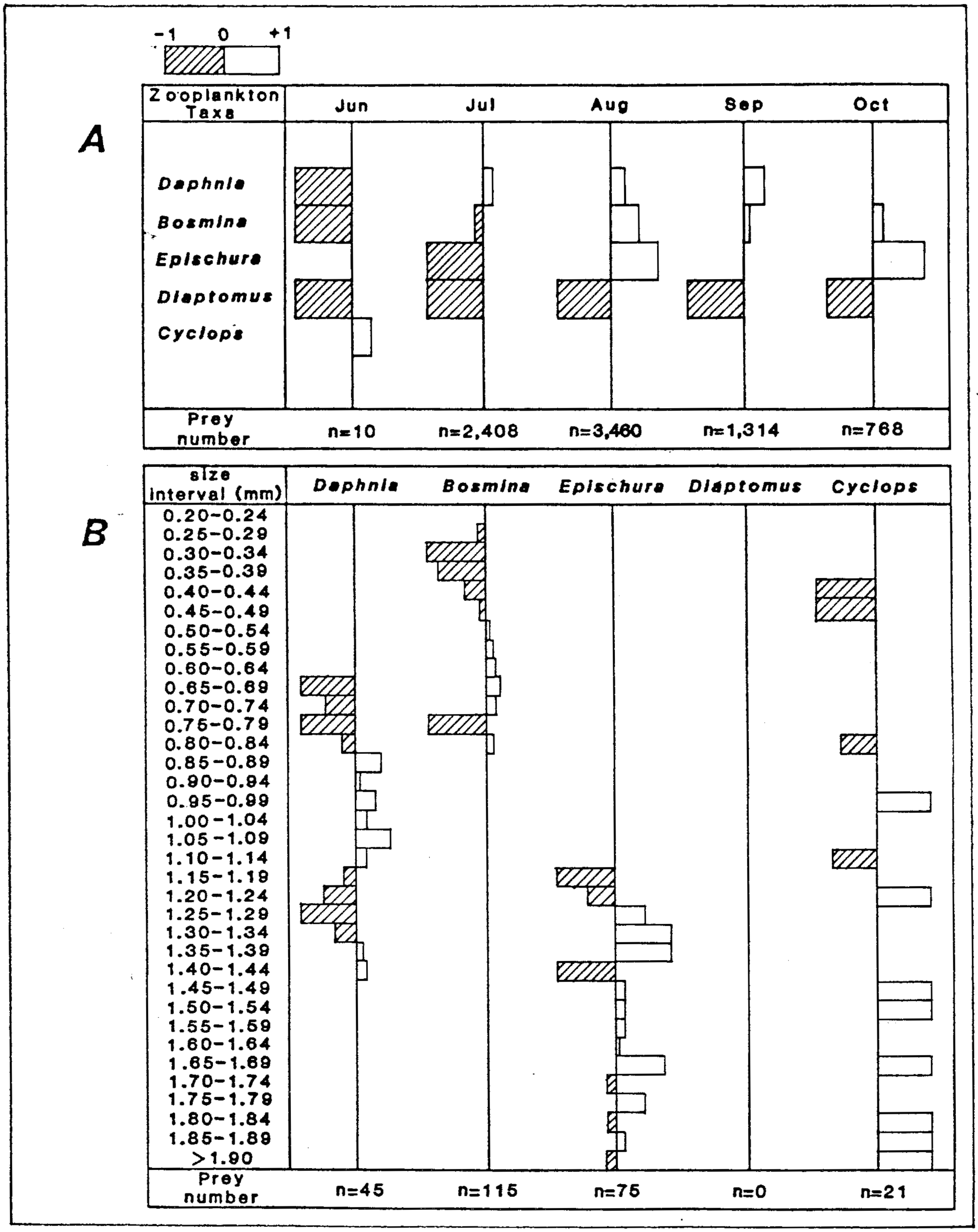

Figure 7. Electivity indices for underyearling coho salmon rearing in Bear Lake during June-October of 1984 by zooplankton taxa (A) and zooplankton body-length by taxa (B).

season (Figure 8A). In fact, the electivity index for three out of the five zooplankton taxa was negative throughout most of the season. Thus, in 1985 because juvenile coho salmon were more littorally distributed, much of the zooplankton was inaccessible as expressed by the negative electivity indices. The size of actively selected zooplankton prey in 1985 varied by taxa as in 1984, and the range was similar to 1984 (Figure 8B).

Seasonal Growth, Prey Composition, and Zooplankton Selectivity of Underyearling Coho Salmon Confined in Net Pens-- In general, daily growth of coho salmon juveniles that reared in the lake and those reared in the pens were quite different; however, the seasonal pattern of daily growth for juveniles reared in the pens and in the lake was fairly similar (Figure 9). Daily growth of fish in the pens decreased initially from the date of stocking (5 June) until the end of June, increased and peaked during July before finally decreasing after mid-August. The major exceptions to this pattern were the daily increase in length of juveniles in pen 1 observed during mid-September, and the increase in daily length and weight of juveniles in pen 2 on the first sample date in October. The timing of peak daily growth for coho salmon rearing in the lake was similar to fish in the pens, but unlike that in the pens, daily growth rates steadily increased, were higher overall until mid-August, and fluctuated less within the season but were higher over the entire season. The seasonal mean daily growth rate of fish that reared in the lake was 0.34 mm in length and 0.9% in weight compared to 0.23 mm and 0.6% for fish reared in both pens 1 and 2 combined. Finally, the condition coefficient of juveniles reared in the pens ranged widely from a low of 0.92 in mid-July for pen 1 to a high of 1.27 in early August for pen 2, and averaged 1.15 in both pens over the season (Figure 9). The seasonal pattern of the condition of coho salmon juveniles that reared in the lake was less dynamic, but did not exceed 1.20, and averaged 1.12 over the season.

For the majority of sample dates (6 out of 10), the size of coho salmon juveniles confined to a diet of zooplankton in pens 1 and 2 during June-October was not significantly (Mann-Whitney U-test; $p = 0.05$) different in either pen (Table 4). The

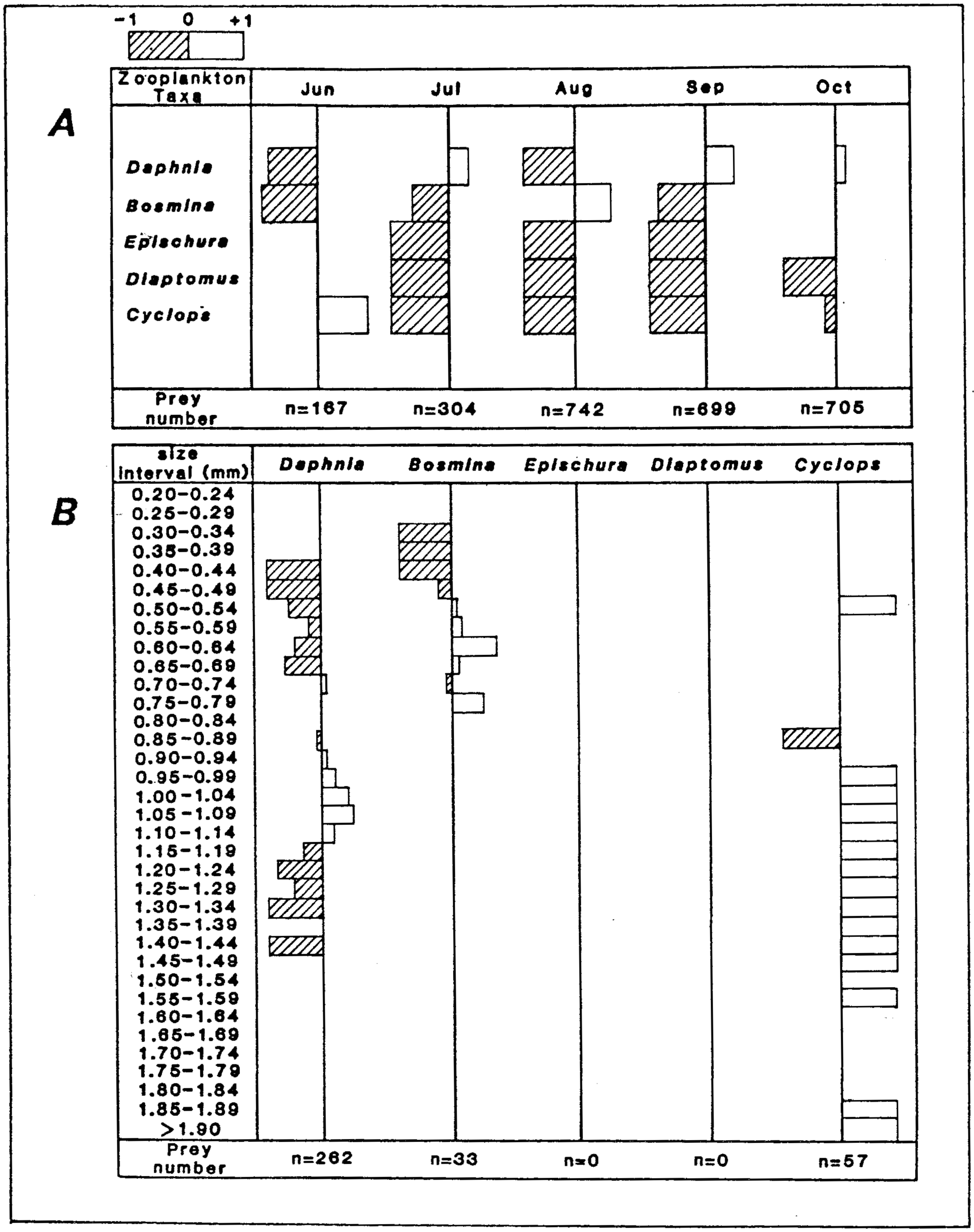

Figure 8. Electivity indices for underyearling coho salmon rearing in Bear Lake during June-October of 1985 by zooplankton taxa (A) and zooplankton body-length by taxa (B).

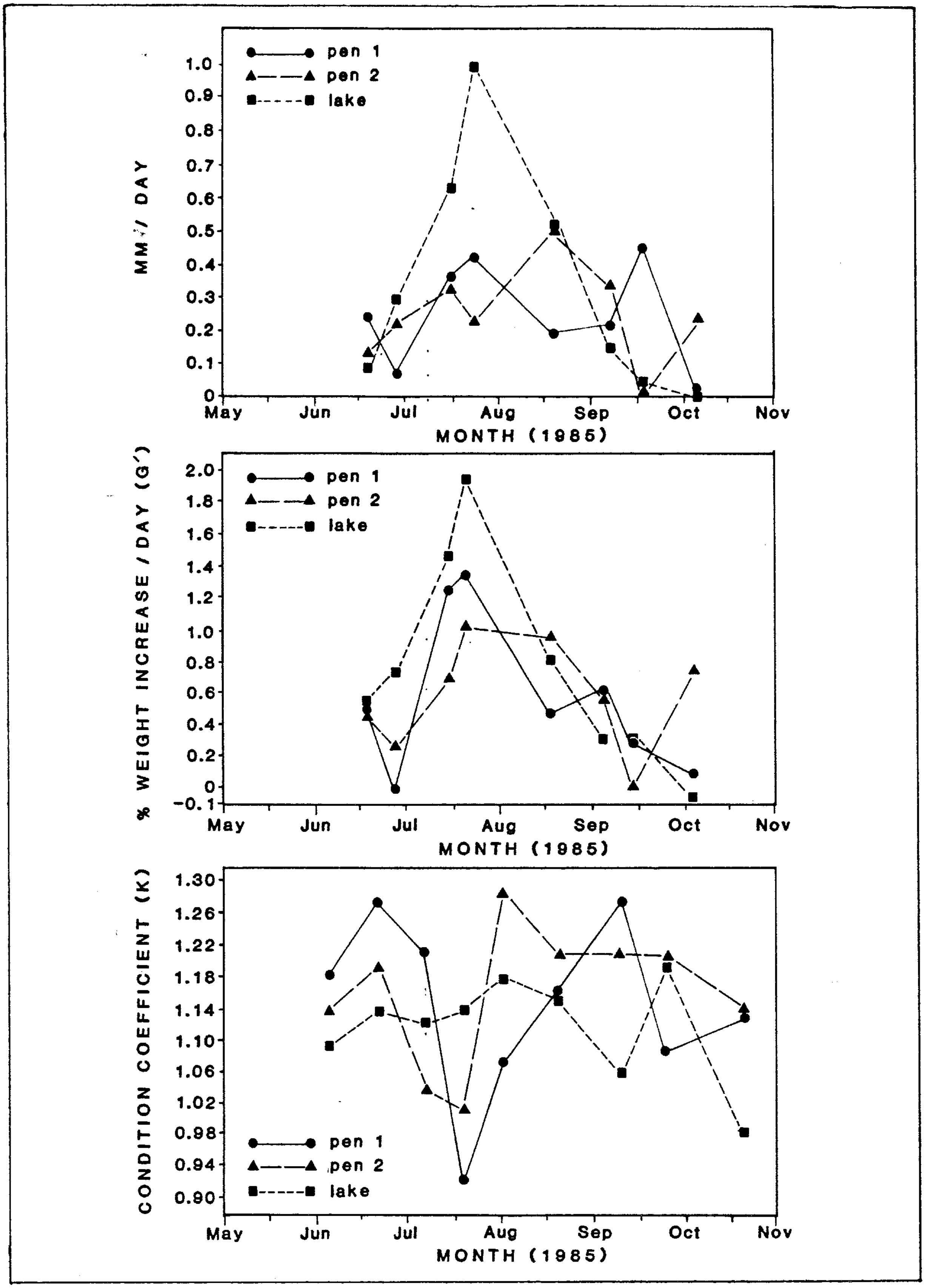

Figure 9. Daily growth rates and seasonal condition coefficients for underyearling coho salmon rearing in Bear Lake and in the net pens during June-October of 1985.

Table 4. Mean size and statistical comparison of size between underyearling coho salmon restricted to zooplankton in the net pens and underyearling coho salmon that reared in the lake during the 1985 growing season.

Sample date	Lake		Pen 1		Pen 2		Pen 1 versus Pen 2		Pens 1 and 2 versus lake	
	Mean length (mm)	Mean weight (g)	Mean length (mm)	Mean weight (g)	Mean length (mm)	Mean weight (g)	Length	Weight	Length	Weight
05 Jun	47	1.1	49	1.4	46	1.1	+	+	+	+
20 Jun	47	1.2	53	1.9	48	1.3	-	-	+	+
03 Jul	51	1.5	54	1.9	51	1.4	+	+	+	+
18 Jul	61	2.6	60	2.0	56	1.8	-	+	-	-
01 Aug	75	5.0	66	3.1	59	2.6	+	+	-	-
22 Aug	86	7.2	70	4.0	70	4.1	+	+	-	-
11 Sep	91	8.1	75	5.4	77	5.5	+	+	-	-
26 Sep	91	9.1	82	6.0	77	5.5	-	+	-	-
22 Oct	95	8.5	83	6.5	84	6.7	+	+	-	-

+ Indicates acceptance of null hypothesis that sizes are not significantly different (Mann-Whitney U-test; $p = 0.05$).

- Indicates rejection of null hypothesis that sizes are not significantly different (Mann-Whitney U-test; $p = 0.05$).

exceptions were the first sample date after planting (20 June), in which both mean lengths and weights of juveniles in pen 1 were significantly greater, and on 18 July and 26 September when the mean lengths of fish in pen 1 were significantly larger than in pen 2. In addition, the comparison between the sizes of coho salmon juveniles in both pens combined and those rearing in the lake over the season, indicated that except for the first two sample dates after planting, the mean length and weight of juveniles in the pens were significantly (Mann-Whitney U-test; $p = 0.05$) smaller compared to the lake (Table 4). Thus, it is evident that juvenile coho salmon rearing in the lake definitely grew at a higher rate, beginning approximately one month after being released, and continuing until the end of the growing season (October) in 1985.

The composition of zooplankton prey of coho salmon juveniles confined in the net pens indicated that, as in the lake, cladocerans were the major zooplankton consumed (Table 5). Second to cladocerans in preference was the copepod *Epischura*, in which compositions reached as high as 58% (18 July) of the total for juveniles reared in pen 2. In contrast, there were very few *Diaptomus* or *Cyclops* found in juveniles confined in pens 1 and 2. The seasonal mean number of zooplankton per fish for both pens combined ranged from 10 to 2,235 organisms, and usually averaged above 2,000 organisms per fish from the end of August through October.

The selectivity of zooplankton prey by coho salmon juveniles in the pens showed that *Daphnia* were almost always actively selected each sample date (except August), while *Bosmina* were actively selected only during the sampling conducted in June and August (Figure 10A). Of the copepods, only *Epischura* were actively selected, and like *Daphnia*, had positive electivity indices throughout the entire season except during the June sampling, which was due to the lack of *Epischura* in the pens as a result of low densities in the lake at that time.

Finally, the overall size of actively selected zooplankton prey in the net pens was similar to that found in the lake during 1984 and 1985, ranging from 0.50 mm for

Table 5. Percent composition (n/N%) and frequency of occurrence (f/n%) of zooplankton prey found in stomachs of underyearling coho salmon confined in the net pens, 1985.

Sample date	Pen number	Sample size	Percentage of fish containing zooplankton	Mean number of zooplankton per fish	Copepoda						Cladocera			
					Epischura		*Diaptomus*		*Cyclops*		*Daphnia*		*Bosmina*	
					(n/N%)	(f/n%)	(n/N%)	(f/n%)	(n/N%)	(f/n%)	(n/N%)	(f/n%)	(n/N%)	(f/n%)
20 Jun	1	10	75	21	0	0	0	0	0	13	97	75	2	25
	2	19	84	5	0	0	0	0	7	26	86	79	6	21
Combined		29	81	10	0	0	0	0	3	22	93	81	4	15
03 Jul	1	10	100	166	0	0	0	0	0	0	100	100	0	40
	2	10	90	89	0	0	1	10	0	0	93	90	6	60
Combined		20	95	129	0	0	0	5	0	0	98	95	2	50
18 Jul	1	10	90	163	38	80	0	0	0	20	59	90	3	80
	2	10	100	322	58	70	0	0	1	30	38	100	2	90
Combined		20	95	393	46	75	0	0	0	25	50	95	3	85
01 Aug	1	10	100	693	41	100	0	0	0	0	56	100	3	80
	2	10	100	598	52	60	0	0	0	0	21	90	26	90
Combined		20	100	645	46	80	0	0	0	0	40	95	14	85
22 Aug	1	10	100	1,947	15	70	0	0	0	0	9	100	76	100
	2	10	100	2,360	24	60	0	0	0	0	17	100	58	100
Combined		20	100	2,235	20	65	0	0	0	0	13	100	67	100
11 Sep	1	10	100	1,800	13	80	3	40	0	0	31	100	54	100
	2	10	100	2,448	35	70	0	0	0	10	17	100	48	100
Combined		20	100	2,124	28	75	1	20	0	5	22	100	49	100
26 Sep	1	10	100	4,077	6	90	1	15	0	0	89	100	3	50
	2	10	100	1,601	41	70	0	0	0	0	56	100	3	90
Combined		20	100	1,670	35	80	1	8	0	0	62	100	2	70
22 Oct	1	14	100	1,942	7	64	0	0	0	0	93	100	0	7
	2	15	100	1,915	14	53	0	0	0	0	86	100	0	7
Combined		29	100	1,928	10	59	0	0	0	0	90	100	0	7

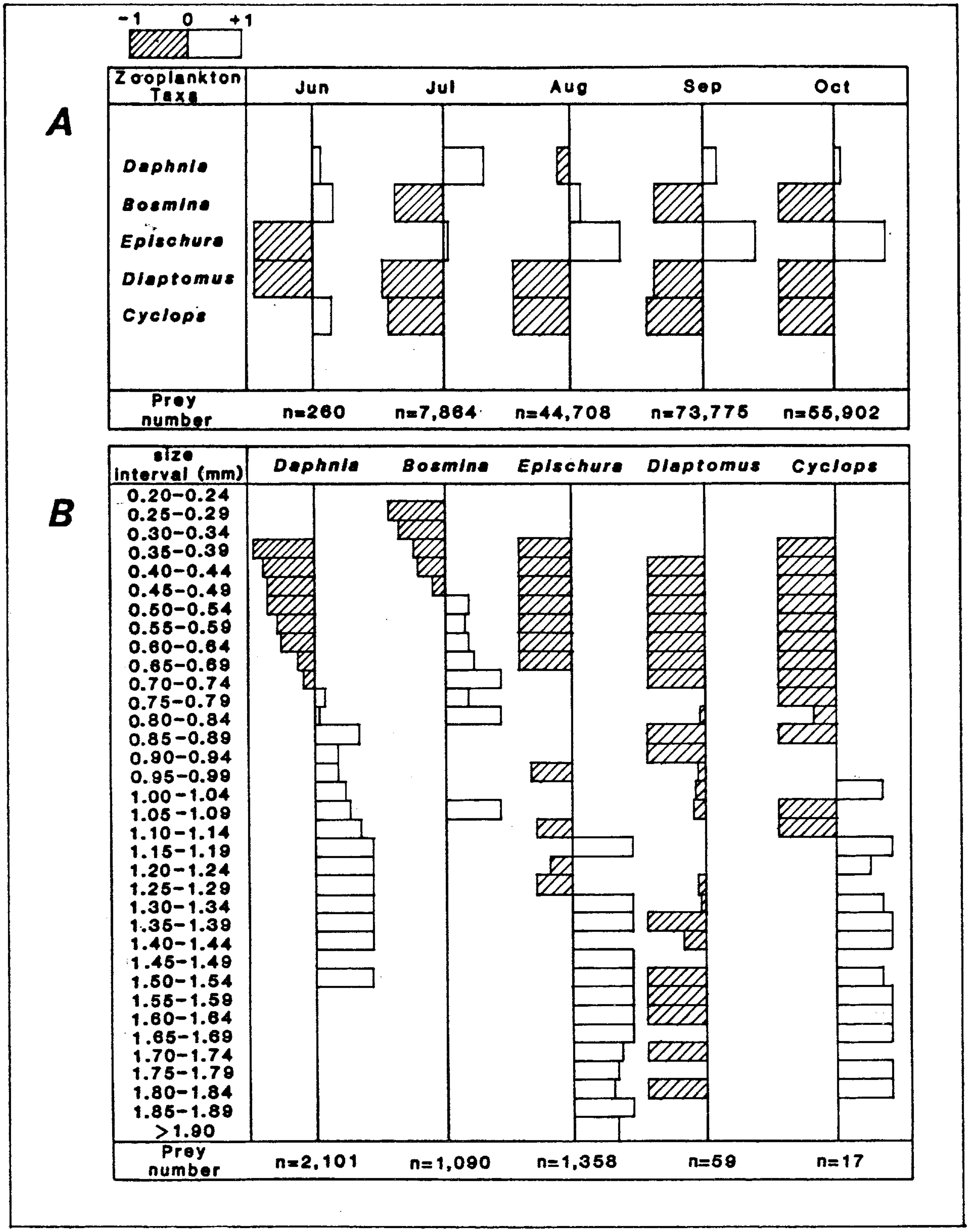

Figure 10. Electivity indices for underyearling coho salmon confined in net pens during June-October of 1985 by zooplankton taxa (A) and zooplankton body-length by taxa (B).

Bosmina to >1.90 mm for *Epischura* (Figure 10B). Because the fish in the pens were restricted to zooplankton prey, there was an opportunity to observe size-selective predation. As observed for juveniles feeding on zooplankton in the lake, juveniles confined to a diet of zooplankton in the pens did not actively select zooplankton smaller than 0.50 mm. In addition, *Daphnia* ranging in body-length from 0.70-1.50 mm, *Bosmina* ranging from 0.50-0.80 mm, *Epischura* ranging from 1.30-1.90 mm, and finally *Cyclops* ranging from 1.15-1.80 mm, were actively selected.

Comparison of Zooplankton Abundance and Size Inside and Outside of Net Pens-- The results of testing for significant (Wilcoxen signed-rank test; $p = 0.20$) difference in zooplankton abundance in 1985 among the net pens containing fish, net pens without fish (controls), and in the lake during June-October are presented in Table 6. With the one exception on 26 September, zooplankton abundance in pens 1 and 2 were not significantly different over the season. In addition, zooplankton abundance in both pens containing fish was not significantly different from the two control nets without fish during the first half of the season (10 June through 1 August). However, after the end of August, zooplankton abundance in pens 1 and 2 was significantly greater than the control pens, and continued to be throughout the remainder of the summer growing season (October). The abundance of zooplankton in the lake was consistently and significantly greater than in the control pens and the pens containing fish for each sample date over the entire growing season. Thus, there was a discrepancy between zooplankton abundance in pens 1 and 2, which contained fish, and in the controls without fish during the first half of the rearing season; nevertheless, zooplankton abundance was significantly less in pens 1 and 2 due to greater predator pressure (i.e., 8 times the stocking density) in the pens than in the lake.

Finally, there were some explicit differences in the size frequency of zooplankton sampled in the net pens with fish, the control pens without fish, and in the lake. For example, the greatest size-class frequency of *Daphnia*, which was the preferred zooplankton of coho salmon rearing both in the lake and in the pens, was 0.45-

Table 6. Statistical comparison of the abundance of zooplankton within the net pens containing fish, without fish (controls), and in the lake during the 1985 growing season.

Sample date	Pen 1 versus Pen 2	Pens 1 and 2 versus controls	Lake versus controls	Pens 1 and 2 versus lake
20 Jun	+	+	-	-
03 Jul	+	+	-	-
18 Jul	+	+	-	-
01 Aug	+	+	-	-
21 Aug	+	-	-	-
11 Sep	+	-	-	-
26 Sep	-	-	-	-
22 Oct	+	-	-	-

+ Indicates acceptance of null hypothesis that zooplankton abundances are not significantly different (Wilcoxen sign-rank test; p = 0.20).

- Indicates rejection of null hypothesis that zooplankton abundances are not significantly different (Wilcoxen sign-rank test; p = 0.20).

0.49 mm in the pens containing fish, 0.50-0.54 mm in the control pens, and 0.90-0.94 mm in the lake (Figure 11). Similarly, size differences in the pens containing fish, the control pens without fish, and in the lake were observed for *Epischura* and *Cyclops*, and to a lessor degree for *Bosmina*. These size differences suggest that perhaps the net pens were a factor in restricting entry of large-size zooplankton, and/or intensive size-selection of zooplankton prey by the high density of rearing juveniles in the pens.

EVALUATION

The potential of juvenile coho salmon to successfully rear and grow on zooplankton was evident from evaluation of the diet of fingerlings rearing in Bear Lake during 1984 and 1985. In 1984, when a substantial number of coho salmon juveniles were limnetically distributed and feeding primarily on zooplankton during the majority of the growing season, the daily growth rate was as high as 0.88 mm in length and 0.17 g in weight. In 1985, when much fewer juveniles were limnetically distributed and the juveniles were feeding more on insects than on zooplankton, at least during mid-September, the greatest daily growth rate was 1.01 mm and 0.17 g. In 1984, 80,000 fewer and larger hatchery fingerlings stocked into Bear Lake produced a significantly ($p = .05$) larger fish at the end of the summer growing season than in 1985 (Table 1); however, the maximal daily growth rates in 1984 and 1985 were quite similar. Thus, it is apparent in Bear Lake that zooplankton provides either a primary or secondary food source for rearing coho salmon and has the potential to affect daily and seasonal fish growth.

Perhaps, if it were not for the depressed production and timing of zooplankton in 1985, presumably due to the late spring (cool temperatures), seasonal and maximal daily growth rates would have been greater in 1985. That is, comparing the seasonal density and peak timing of total macro-zooplankton (cladocera and copepods) in 1984 and 1985; it is evident that neither the early vernal pulse nor the magnitude of production occurred in 1985, when the lake temperature was cooler (Figure 12).

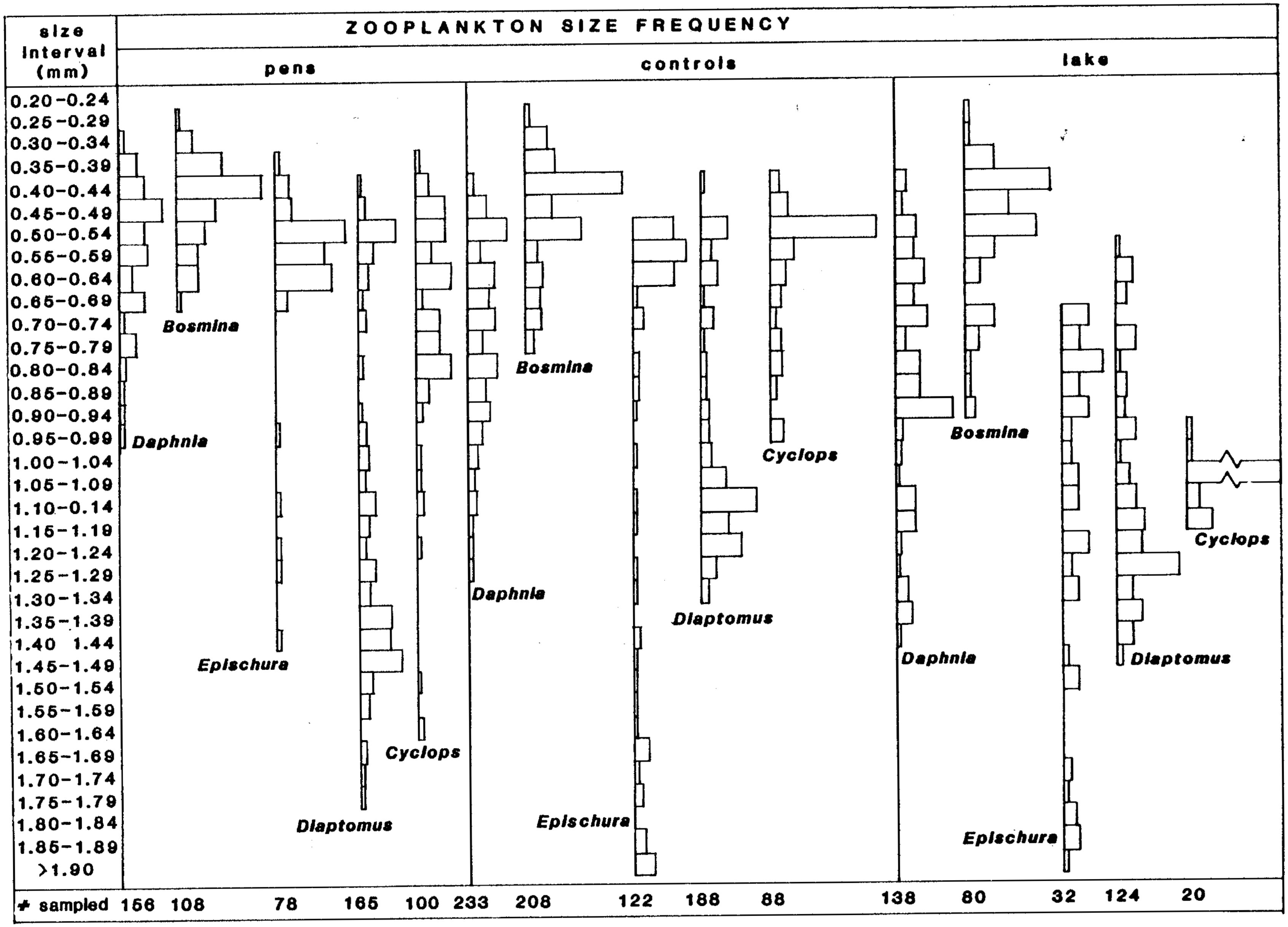

Figure 11. Comparison of zooplankton size frequency in the net pens with fish, in the net pens without fish (controls), and in Bear Lake.

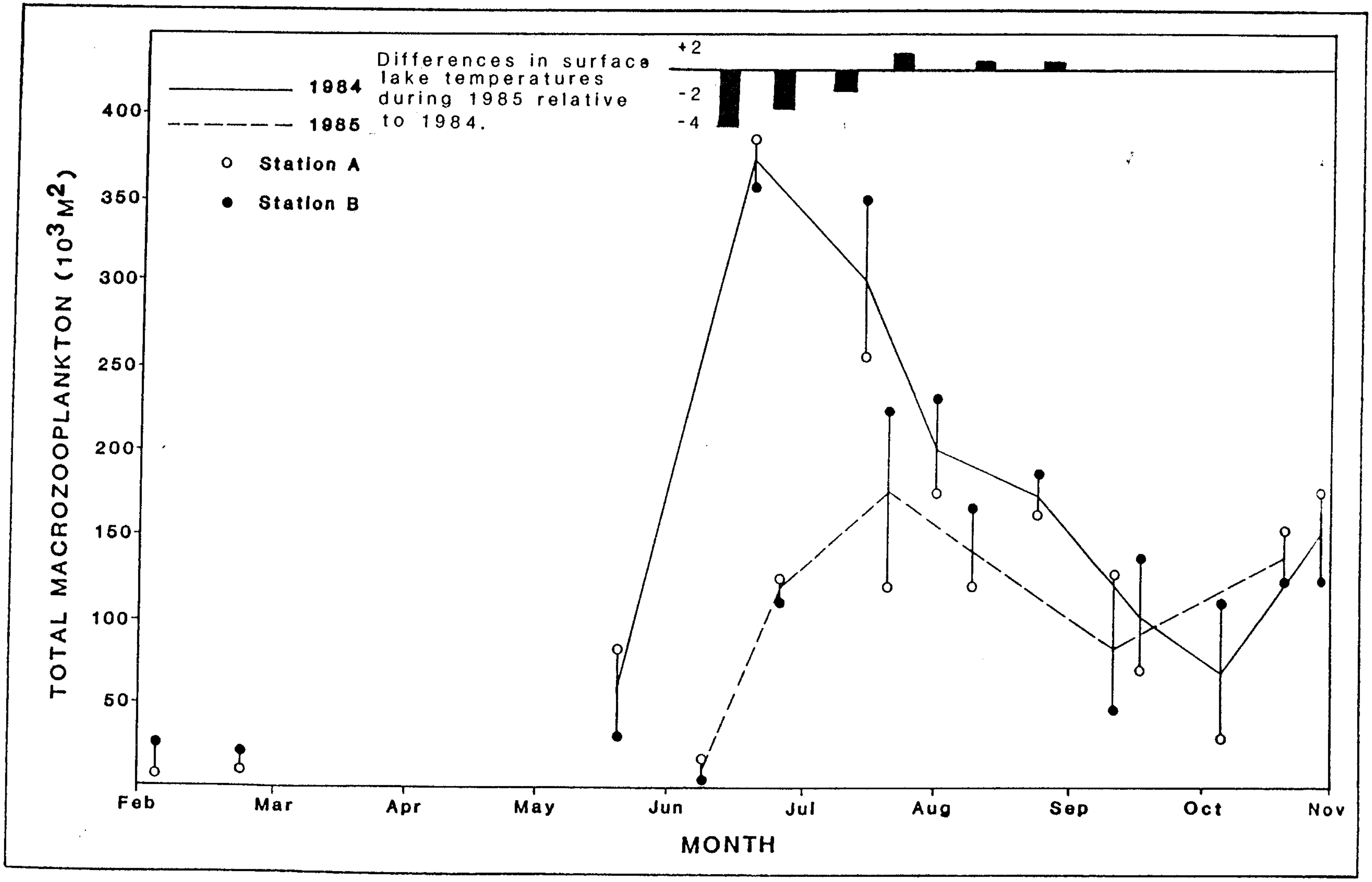

Figure 12. Comparison of seasonal density (10^3 organisms/m^2) of macro-zooplankton (cladocerans and copepods) in Bear Lake at Stations A and B, and differences in lake temperatures (C) during 1985 relative to 1984.

Thus, the absence of an early zooplankton pulse and depressed seasonal production apparently curtailed the migration of fish to the limnetic area of Bear Lake in 1985. The virtual absence of juvenile coho salmon in the limnetic area because of low zooplankton abundance is not unique; Crone (1981) observed the same phenomena in one of three barriered lakes in Southeast Alaska. Of the three lakes Crone (1981) studied, Ludvik Lake had the lowest seasonal zooplankton abundance and the sharpest decline in zooplankton during the late summer and early fall. In addition, juvenile coho salmon were distributed mainly alongshore and fed primarily on insects throughout the season. In contrast, in Tranquil and Osprey Lakes, juvenile coho salmon were observed offshore and fed mainly on zooplankton during the peak of the summer growth season. The yield in terms of smolt biomass (kg/ha) was 8-fold less in Ludvik Lake than the average of Tranquil and Osprey Lakes, in which juvenile coho salmon were found offshore and feeding on more abundant zooplankton later in the season. Thus, the availability of food (i.e., zooplankton) appears to influence the distributional behavior and feeding of juvenile coho salmon rearing in lakes. In addition, limited zooplankton abundance, particularly during the summer and early fall, can affect pre-smolt growth, and, in turn, growth can affect survival and the desirable production of age-1 smolts.

The pen rearing study of 1985 provided evidence that rearing coho salmon restricted to a zooplankton diet can not only survive over the summer until mid-fall, but also can grow to a respectable size; despite a relatively high fish density and the possibility of limited entry of large-size zooplankton in the pens. In each pen, a stocking density of more than 8 times that in the lake was represented by the 20 coho salmon juveniles, yet combined, 72.5% (29 of the 40) of the juveniles survived over the rearing season to the last sample date on 22 October. In addition, the sizes and growth rates were significantly less ($p = 0.05$) for fish confined in the pens compared to fish rearing in the lake over the season (Table 4); however, the fish in the pens were far from an emaciated condition, as the condition coefficient of the penned fish averaged 1.15, while that for fish rearing in the lake averaged 1.12 over the season. Thus, the net pens allowed rearing juveniles to feed in relatively good food conditions, survive at a relatively high rate, and grow relatively good compared to cohorts rearing in the lake; despite withstanding the stress of anesthetization and gastric lavage.

Finally, the peak daily growth of juvenile coho salmon rearing in the lake during 1984, when the fish fed primarily on zooplankton, and the net pen study, exemplified the ability of underyearling coho salmon to survive and grow on zooplankton. To take full advantage of the zooplankton food source, the ideal stocking strategy would be dependent on the release of coho salmon fingerlings into a lake at a time when the presence and density of zooplankton forage of the preferred type and size (e.g., *Daphnia*, and *Bosmina* >0.70 mm and *Epischura* >1.25 mm) allow for maximum food intake relative to the cost of energy expended in foraging. This requires stocking when conditions in the lake are favorable, such as a seasonally early zooplankton pulse and a robust zooplankton population throughout the summer growing season, which, as observed in Bear Lake, can vary temporally depending upon climatological conditions (as well as autochthonous production).

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